# DEVELOPMENT OF STONE MASTIC ASPHALT WITH HIGH PERFORMANCE ASPHALT FOR PREVENTION OF REFLECTIVE CRACKING

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**ABSTRACT**

Many reflective cracking inhibition methods using sheets, grids or stress absorbing membranes have been applied for the existing concrete slab pavements or asphalt pavements with sever cracks.

Stone Mastic Asphalt (SMA) with high performance asphalt is developed for prevention of reflective cracking. The binder that is 177 in penetration and 84 degree Celsius in softening point ($T_{R\&B}$) is a high–content- SBS modified asphalt with a new additive.

On a national highway in Fukushima Prefecture north of Tokyo, two test sections were built in March 2007. The objective was to observe asphalt overlays on concrete slab pavements. The highway was designed for a traffic volume of 1000 heavy vehicles per day. One of the test sections consisted of a 5-cm thick SMA overlay and the other consisted of a 5-cm thick dense graded asphalt concrete plus 1-cm thick Stress Absorbing Membrane Interlayer (SAMI). Visual inspection was conducted after one year. The percentage of reflective cracks initiated was 6.8% in the SMA section and 46.1% in the asphalt concrete section. In addition, the SMA overlay was applied to another concrete pavement. No or little reflective cracking was observed in the SMA.

From these observations, it could be concluded that the SMA with high performance asphalt might be useful for overlays to prevent reflective cracking on concrete pavements.

## 1. INTRODUCTION

In Japan, the asphalt overlay method is often used as a way of repairing concrete pavements because it is relatively low in cost and enables early opening to traffic. However, there are some reported cases of reflective cracks initiated right above the joint between concrete slabs at an early date after repair work. For prevention of this reflective cracking, such methods as to use sheets, grids or stress or to provide a stress absorbing membrane interlayer (SAMI) are available. In addition, not a few research results have hitherto been applied therefore.

We developed a new reflective cracking inhibition method, i.e.., a technique of imparting a reflective cracking inhibition capability to the asphalt overlay itself and verified its applicability on an in-service road.

In concrete terms, this method is to apply a Stone Mastic Asphalt (SMA) with a high - performance asphalt improved greatly in temperature susceptibility and stress relaxation to part or all of the asphalt overlay.

This paper reports on the “laboratory test results” and “verification results on the applicability on an in-service road related to the reflective cracking inhibition effect.

## 2. EXISTING REFLECTIVE CRACKING INHIBITION METHODS

The cause of reflective cracking of the asphalt overlay on a concrete slab is considered to be a result from the combined behaviors of:

- Horizontal displacement by expansion and shrinkage with changes in concrete slab temperature.
- Deflection due to temperature difference in the concrete slab.
- Vertical displacement under traffic loads.

Typical methods currently applied for prevention of this reflective cracking are as follows:

1) Method of increasing the paving thickness of the asphalt overlay to restrain the movement of the concrete slab by the temperature change and passage of vehicles or method of delaying the time for cracks initiated at the under surface of the pavement to reach the road surface.
2) Method of placing glass grids, bituminous crack inhibiting sheets, etc. between the existing concrete slab and the asphalt overlay to relax stress or strain at the under surface of the overlay.
3) Method of providing a stress relaxing layer of mastic mixture, modified asphalt emulsion or asphalt rubber between the existing concrete slab and the asphalt overlay to relax stress or strain at the under surface of the asphalt overlay.
4) Method of providing a layer of porous asphalt mixture, which relaxes the movement of the joint, etc. of the existing pavement, in the lower part of the overlay.

These methods are characterized in that a layer for reflective cracking inhibition is provided, with the exception of the method of 1) that increases the pavement thickness. In contrast, the newly developed method imparts a reflective cracking inhibition capability to the asphalt overlay itself. It can also be expected that this method will simplify work procedures and shorten work periods.

## 3. DEVELOPMENT OF REFLECTIVE CRACKING INHIBITION METHOD

### 3.1 Background

In order to impart a reflective cracking inhibition capability to the overlay, we developed a high-performance asphalt improved in temperature susceptibility and stress relaxation.

The high - performance asphalt is a polymer-modified asphalt with a special additive, in addition to SBS (styrene-butadiene copolymer) generally used as a modifier. It was developed on the basis of the following concepts:

- Decrease the temperature susceptibility of asphalt as far as possible to maintain the stress relaxing capability and flexibility of asphalt mixtures in a wide temperature range from low to normal temperatures.
- Ensure resistance to deformation by flow as well.
- Make it possible to produce and apply a mixture with the high-performance asphalt in the same manner as ordinary modified asphalts.

In addition, SMA was selected as a kind of asphalt mixture for the following reasons:

- High in optimal asphalt content as compared with ordinary mixtures. Therefore, the characteristics of the asphalt used are easily reflected in the mixture.
- Easy to ensure resistance to deformation by flow as mentioned in the concept of the ensure resistance to deformation.

The properties of the high - performance asphalt and the SMA with it (hereinafter called “HP-SMA”) are exemplified below.

### 3.2 Properties of the high - performance asphalt

A comparison of the typical properties of the high-performance asphalt with those of the straight asphalt 60/80 (hereinafter called “straight asphalt”) and polymer-modified asphalt type II (hereinafter called “type II asphalt”) is given in Table.1.

**Table.1** Typical properties of the high - performance asphalt

| | Unit | High-performance asphalt | Type II asphalt | Straight asphalt 60/80 |
|---|---|---|---|---|
| Penetration (25 degree Celsius) | 1/10 mm | 177 | 55 | 69 |
| Softening point | degree Celsius | 84.0 | 61.5 | 48.0 |
| Ductility (15 degree Celsius) | cm | 100+ | 86.0 | 100+ |
| Ductility (4 degree Celsius) | cm | 90 | 54 | 7 |
| Fraass brittle point | degree Celsius | -23 | -11 | -12 |
| Viscosity of 60 degree Celsius | Pa・s | 11,300 | 1,457 | 208 |
| Bending strain (-10 degree Celsius) | ($x10^{-3}$) | 384 | - | 49 |

As seen from Table.1, high-performance asphalt has the following characteristics:

- The penetration of 177 is more than 100 (1/10 mm) as great as that of the type II asphalt.
- Despite the greater penetration, the softening point is 84.0 degree Celsius, i.e., about 20 degree Celsius higher than that of the type II asphalt. In other words, the temperature susceptibility is lower.
- The Fraass brittle point is about 10 degree Celsius lower than that of the straight asphalt 60/90 and type II asphalt. In addition, the ductility at 4 degree Celsius and bending strain at -10 degree Celsius are greater. Therefore, the high-performance asphalt is resistant to brittleness at low temperature and excellent in flexibility.

The data on m-value obtained by the Bending Beam Rheometer (BBR) test are given in Figure. 1. The m-value indicates the degree of decrease in stiffness with a changes in time. The greater m-value shows higher stress relaxing capability.

The m-value of the high-performance asphalt is about twice as great as that of the straight asphalt 60/80 and type II asphalt, which indicates a high degree of stress relaxation in the low-temperature region.

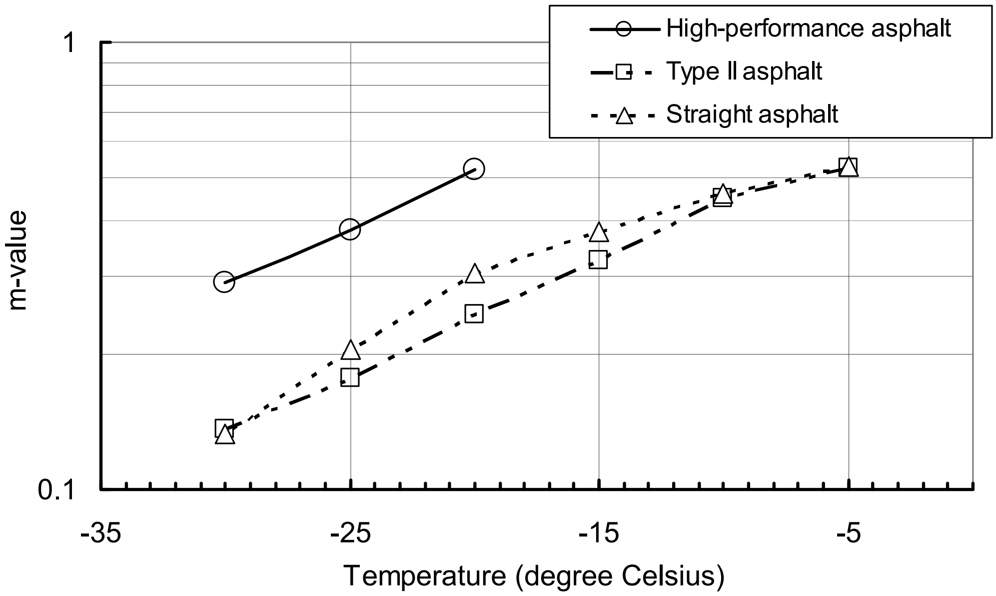



Figure.1 BBR test results (m-value)

### 3.3 High Performance Stone Mastic Asphalt

The asphalt content and composite aggregate grading and the Marshall properties of the HP-SMA are given in Tables.2 and 3.

**Table.2** Asphalt content and combined aggregate grading

| Asphalt content (%) | Sieve opening (mm) and passing percent mass (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 19.0 | 13.2 | 4.75 | 2.36 | 0.600 | 0.300 | 0.075 |
| 5.7 | 100.0 | 98.8 | 40.7 | 27.5 | 18.9 | 16.3 | 11.0 |

**Table.3** Marshall properties

| Item | Unit | Property value |
|---|---|---|
| Asphalt content | % | 5.7 |
| Void ratio | % | 2.6 |
| Stability | KN | 6.5 |
| Flow value | 1/100 cm | 29 |

Figure.2 shows the breaking strain by the flexural test.

The HP-SMA has a flexural fracture strain 4-8 times greater than that of the asphalt concrete (max. grain size: 13 mm) with the type II asphalt commonly used for heavy traffic roads (hereinafter called "modified type II asphalt concrete"). Moreover, it shows a flexural fracture strain 2-5 times greater than that of the SMA of the same aggregate grading with the type II asphalt (hereinafter called "modified type II SMA). Therefore, it is a mixture excellent in flexibility.

As shown in Table.4, the dynamic stability of wheel tracking test (photo.1) for the HP-SMA is 5,250 (cycles/mm), so it satisfies the target value of 3,000-5,000 (cycles/mm) when the traffic volume of heavy vehicles is more than 3,000 (units/day/direction) as specified in the Manual for Design and Application of Mixtures with Modified Asphalt [2].

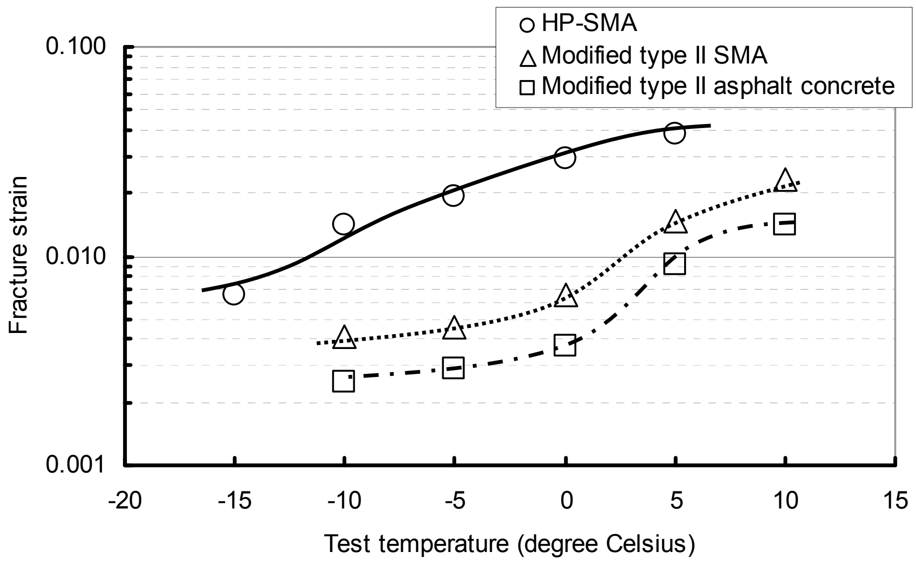



Figure.2 Fracture strain by flexural test

**Table.4** Dynamic stability

| Kind of mixture | HP-SMA | Modified type II SMA | Modified type II asphalt concrete |
|---|---|---|---|
| Dynamic stability (cycles/mm) | 5,250 | >6,000 | >6,000 |

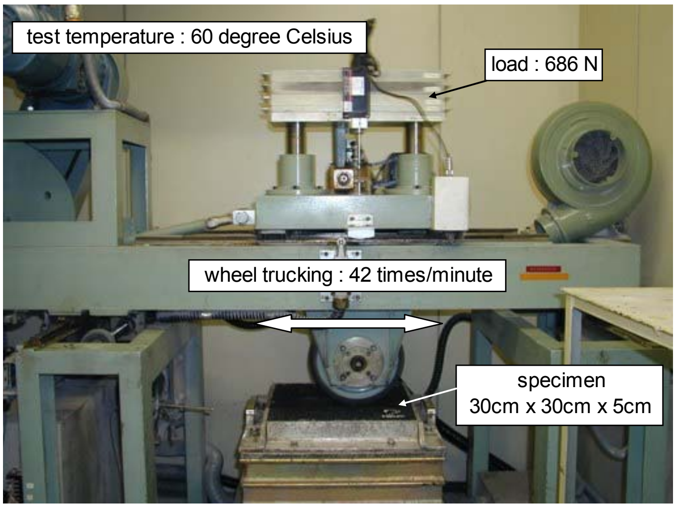



Photo.1 Testing state of wheel trucking test

## 4. VERIFICATION OF REFLECTIVE CRACKING INHIBITION EFFECT OF HIGH PERFORMANCE STONE MASTIC ASPHALT

### 4.1 Conception of the verification method

In order to verify the reflective cracking inhibition effect, we carried out :
1) Flexural fatigue test, 2) Flexural fatigue test on two-layer specimen, 3) Crack propagation test by reference to the testing method devised by the former Construction Ministry's Public Works Research Institute.

In the flexural fatigue test on two-layer specimen of 2) above, we determined the relation between the layers (upper and lower), to which the HP-SMA was applied in a pavement structure, and the cracking inhibition effect. In the crack propagation test of 3), we evaluated the growth retarding effect on cracks initiated under traffic loads.

#### 4.1.1 Flexural fatigue test

The flexural fatigue test was carried out under the test conditions of Table.5.

**Table.5** Flexural fatigue test conditions

| | |
|---|---|
| Loading method | 4-point bending |
| Specimen size | 4 cm thick x 4 cm wide x 40 cm long |
| Span | 30 cm |
| Test method | Strain control |
| Test temperature | 5degree Celsius |
| Applied strain | 300μ, 500μ, 700μ |
| Frequency | 5 Hz |

#### 4.1.2 Flexural fatigue test on two-layer specimen

The flexural fatigue test on two-layer specimen was devised, taking into consideration the fact that reflective cracks are initiated at the under surface of the pavement. To reproduce repeated tension of the under surface of the pavement, tests were done by applying the flexural fatigue test under loading conditions in which to cause displacement in one direction (downward) only.

A schematic view of the test is given in Figure.3 and specimens and test conditions are shown in Table.6.

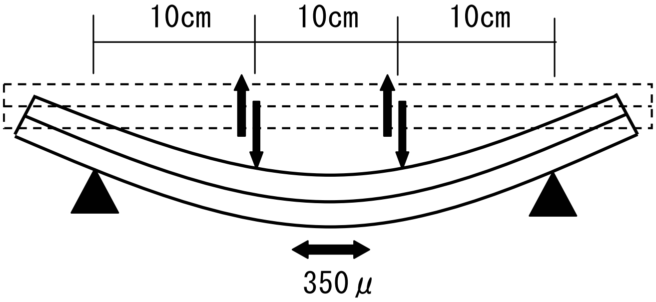



Figure.3 Schematic view of the test

**Table.6** Kinds of specimens and test conditions

| | |
|---|---|
| Loading method | 4-point bending |
| Specimen size | 2+2 cm thick x 4 cm wide x 40 cm long |
| Span | 30 cm |
| Test method | Strain control |
| Test temperature | 5 degree Celsius |
| Strain | 350μ |
| Frequency | 5 Hz |
| Specimen | Upper & lower layers : Modified type II SMA<br>HP-SMA (upper) + Modified type II SMA (lower)<br>Modified type II SMA (upper) + HP-SMA (lower)<br>Upper & lower layers : HP-SMA |

### 4.1.3 Crack propagation test

The crack propagation test uses a wheel tracking test machine. This test was performed with reference to the test method of the former Construction Ministry's Public Works Research Institute. Specifically, a slit was made in the test mixture itself to concentrate stresses under traffic loads on the central part. In addition, this test was characterized in that crack growth was accelerated by placing the specimen directly on a rubber support.
The test conditions are given in Table.7 and the testing state is shown in Photo.2.

**Table.7** Test conditions

| | |
|---|---|
| Specimen size | 5 cm thick x 8 cm wide x 30 cm long |
| Test temperature | 25 degree Celsius |
| Traveling distance | 15 cm |
| Tracking speed | 50 cycles/min |
| Hardness of rubber support (JIS) | 30 |

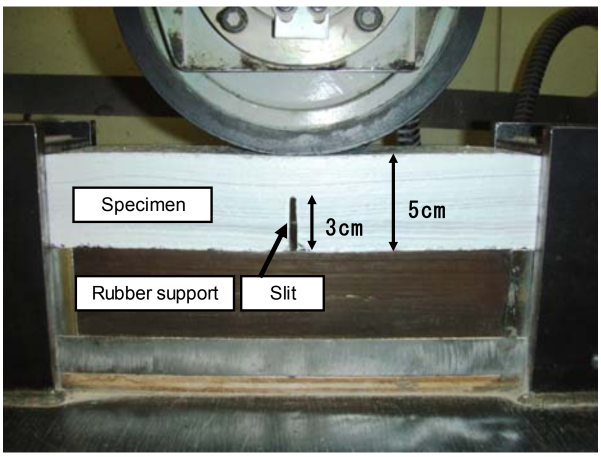



Photo.2 Testing state of crack propagation test

### 4.2 Verification results

#### 4.2.1 Results of flexural fatigue test

(1) Resistance to fatigue cracking
The number of load cycles to rupture obtained from the flexural fatigue test is given in Table.8.
The HP-SMA was not ruptured even when the number of load cycles exceeded 1,000,000 at strain levels of 300μ and 500μ. The number of load cycles to rupture at 700μ was more than 100 times as great as that of the modified type II asphalt concrete and modified type II SMA. Therefore, HP-SMA has high resistance to fatigue cracking.

**Table.8** Number of load cycles to rupture

| Strain level | 300μ | 500μ | 700μ |
|---|---|---|---|
| HP-SMA | 1,000,000+ | 1,000,000+ | 133,067 |
| Modified type II SMA | 121,200 | 5,215 | 704 |
| Modified type II asphalt concrete | 41,945 | 3,791 | 981 |

(2)Stress relaxation
An example of the load-displacement curve (hysteresis curve) obtained from the flexural fatigue test is given in Figure.4.

The historic damping ratio “h” shown in the concept of Figure.5 is one of the indicators of the stress relaxing capability of a viscoelastic structure.

The historic damping ratios of the modified type II asphalt concrete and modified type II SMA were both about 0.2. In contrast, the historic damping ratio of the HP-SMA was 0.4, i.e., twice as great as the above value. Therefore, HP-SMA proved to be excellent in stress relaxation.

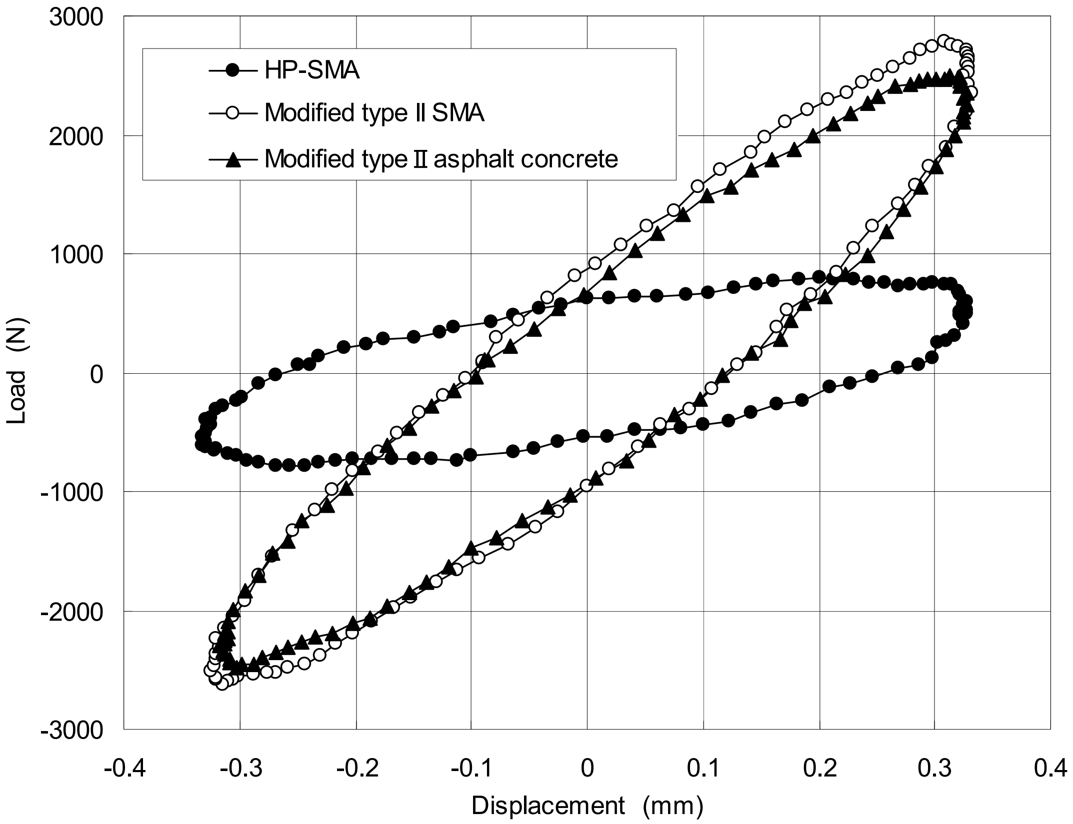
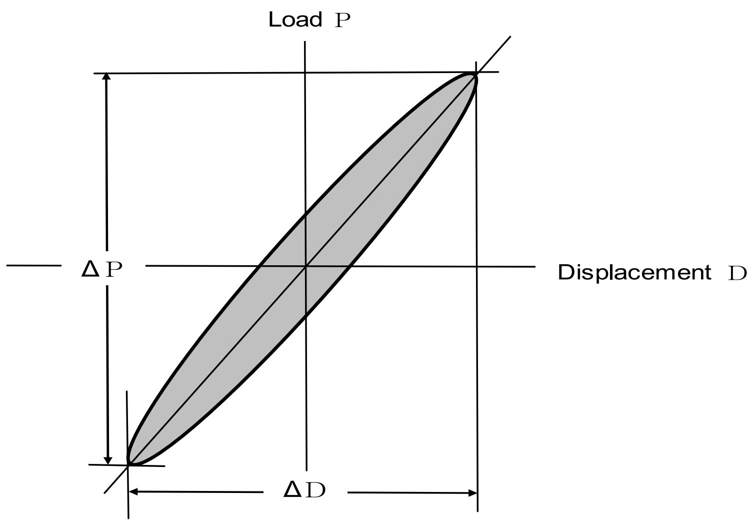



Figure. 4 Example of the hysteresis curve




| |
|---|
| Damping energy ΔW ：area encircled curve<br>Equivalent elastic potential energy W＝ （ΔP ×ΔD） ／8<br>Historic damping ratio h ＝1／4・ΔW／W |

Figure. 5 Concept of the lost energy

#### 4.2.2 Results of flexural fatigue test on two-layer specimen

As shown in the test conditions of Table 6, tests were carried out, assuming the HP-SMA to be applied to three versions of layers, (1) upper layer, (2) lower layer and (3) upper and lower layers. Moreover, a comparative test was done on a specimen to both the upper and the lower layers of which the modified type II SMA was applied.

Figure.6 shows the number of load cycles to rupture by layer configuration.

The number of load cycles to rupture in the case of the HP-SMA applied to the lower layer was about 4 times greater than that in the case of the mixture applied to the upper layer. Therefore, applying the mixture to the lower layer can be assumed to be effective as is presumable from the fact that the method of providing a stress relaxing layer between the two layers has come into common use.

In the case of the HP-SMA applied to the upper layer, the lower layer and both the upper and the lower layers, the number of load cycles to rupture was about twice, about 8 times and more than 40 times, respectively, as great as that in the case of the modified type II SMA applied to both the upper and the lower layers.

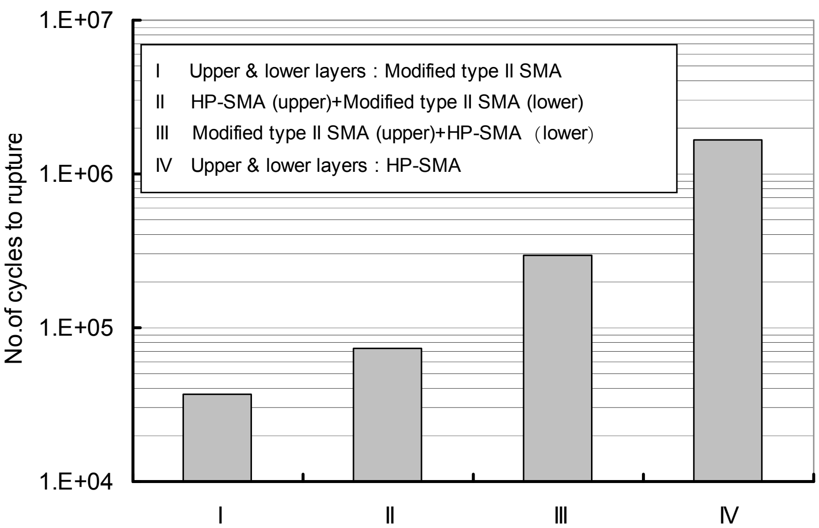



Figure. 6 Results of bending fatigue test on two-layer specimen

#### 4.2.3 Crack propagation test

In the crack propagation test, the time for a crack initiated at the slit of the specimen under traffic loads to reach the specimen surface was measured and evaluated as the No. of cycles to appearance of crack in surface of specimen.

Figure.7 shows the No. of cycles to appearance of crack in surface of specimen. As seen from this figure, the No. of cycles of the HP-SMA is about twice as great as that of the modified type Ⅱ SMA, which indicates that the effect of retarding crack growth is high.

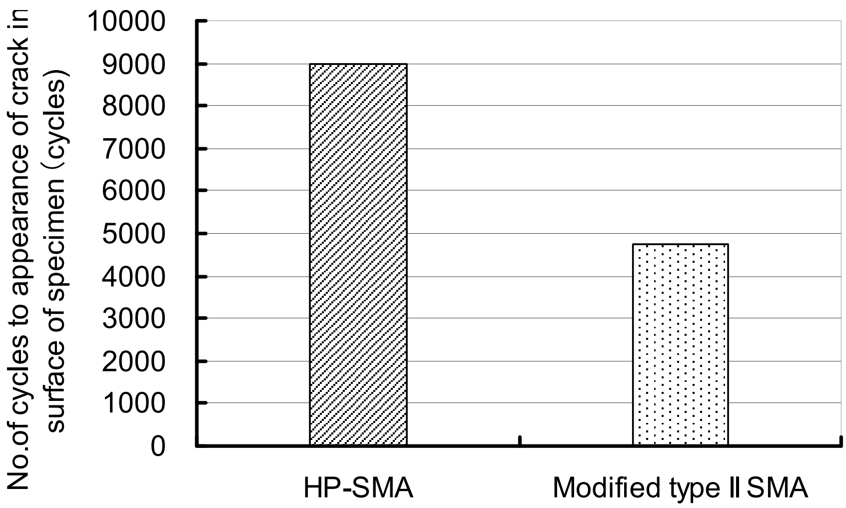



Figure.7 No. of cycles to appearance of crack in surface of specimen

## 5. VERIFICATION ON IN-SERVICE ROAD

A case example of application to in-service road and the in-service conditions of the HP-SMA are shown below.

### 5.1 Case example of application to entire overlay

#### 5.1.1 Contents of the construction work

On a national highway in Fukushima Prefecture north of Tokyo, the asphalt pavement on the concrete slab was repaired by the method of overlay after scarification. Here, the method of applying a single layer of the HP-SMA to the surface course was adopted as a way of inhibiting reflective cracking.

The contents of this construction work are shown Table.9 and Figure.8.

**Table.9** Details of the construction work

| | |
|---|---|
| Time | March 2007 |
| Area | Inbound and downbound lanes 5,625 $m^2$ each (traffic volume of heavy vehicles: more than 1,000 units/day) of which 2,625 $m^2$ was occupied by paving section with HP-SMA. |
| Pavement structure | as shown in Figure.8 |

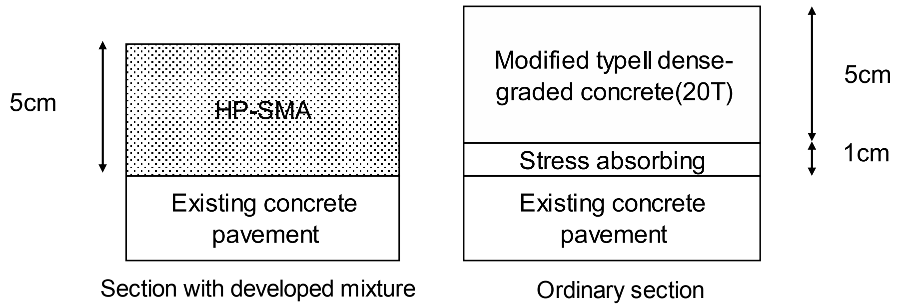



Figure. 8 Pavement structure

### 5.1.2 In-service conditions

In April 2008, about one year after opening to traffic, an investigation was made on the initiation conditions of reflective cracks.

The crack initiation conditions at the joints between the existing concrete slabs were classified by degree as shown in Table 10, and the crack initiation ratio was calculated by degree of initiation.

The crack initiation ratio is the percentage of the number of cracked joints to the total number of joints.

The crack initiation ratio is shown in Figure.9.

**Table.10** Classification of crack initiation conditions

| | |
|---|---|
| Class I | No cracks |
| Class II | Cracks initiated on less than 1/2 of lane width |
| Class III | Cracks initiated on more than 1/2 (incl.) of lane width |
| Class IV | Cracks initiated over entire lane width |

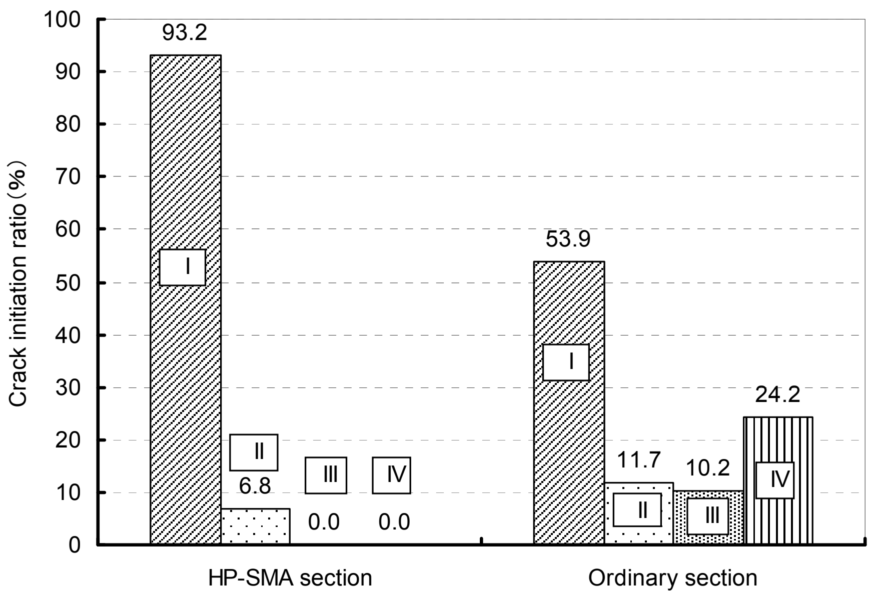



Figure. 9 Crack initiation ratio

As seen from Figure 9, in the ordinary paving section, reflective cracks over the entire lane width, classified as class IV, were initiated at 24.2% of the joints. The ratio of the joints at which reflective cracks including those of class II and III were initiated was 46.1%.

In contrast, in the paving section with the HP-SMA, cracks classified as class IV and III were not initiated. Only cracks on less than 1/2 of the lane width, classified as II, were initiated at 6.8% of the joints.

### 5.2 Case example of application to the underpart of the overlay

#### 5.2.1 Contents of the construction work

This construction work was executed on a prefectural highway in Shizuoka Prefecture southwest of Tokyo. The objective was to scarify and overlay a 6-cm thick surface of the existing 15-cm thick asphalt pavement on the concrete pavement. Here, it was requested to provide simple surface drainage and noise reduction, in addition to reflective cracking inhibition.

Therefore, we adopted a cross section that consists of a 4-cm thick layer of the HP-SMA as the base course and a 2-cm thick layer of porous asphalt concrete (maximum aggregate size : 13mm) as the surface course.

However, the value of 2.5 times the maximum aggregate size could not be obtained with the surface course thickness of 2 cm, so an attempt was made to integrate the upper and lower layers by applying a multi asphalt paver capable of making two layers at a time. The contents of this construction work are shown Table.11 and Figure.10.

**Table.11** Contents of the construction work

| | |
|---|---|
| Time | December 2006 |
| Area | 2,200 $m^2$ (traffic volume of heavy vehicles: more than 1,000 units/day) Entire section paved by this method. |
| Pavement structure | As shown in Figure.10 |

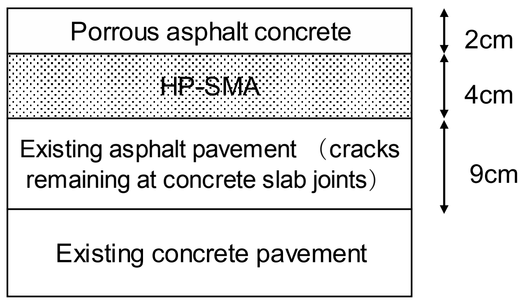



Figure.10 Pavement structure

#### 5.2.2 In-service conditions

According to the investigation results on the surface properties one year after opening to traffic, there was no evidence of reflective crack initiation. As for the surface roughness, the values of σ by 3m profilometer showed only a slight change from 0.8 mm to 1.0 mm according to the measurement results right after opening to traffic. Therefore, good surface properties were maintained. Moreover, according to the observation results obtained more than two years after opening to traffic, there were no reflective cracks as well.

## 6. SUMMARY

### 6.1 Properties of the high-performance asphalt

As compared with the straight asphalt and type II asphalt, the high-performance asphalt is:

1) About 20degree Celsius higher in softening point and lower in temperature susceptibility despite that it is more than 100 (1/10 mm) greater in penetration.
2) About 10degree Celsius lower in Fraass brittle point and greater in ductility at 4degree Celsius and bending strain at -10degree Celsius.
3) About twice in m-value by BBR test

## 6.2 Properties of the HP-SMA

1) The fracture strain by the flexural test is 4-8 times greater than that of the modified type II asphalt concrete and 2-5 times greater than that of the modified type II SMA.
2) The dynamic stability by wheel tracking test is a little more than 5,000 (cycles/mm), so this mixture has a rutting resistance appropriate for application for heavy traffic lanes.
3) In the flexural fatigue test, the HP-SMA is not ruptured even when the number of load cycles exceeds 1,000,000 at strain levels of 300μ and 500μ. The number of load cycles to rupture at 700μ is more than 100 times as great as that of the modified type II asphalt concrte and modified type II SMA.
4) The historic damping ratio of the HP-SMA, calculated from the hysteresis curve in the flexural fatigue test, is about twice as high as that of the modified type II asphalt concrete and modified type II SMA.
5) The No. of cycles to appearance of crack in surface of specimen is about twice as great as that of the modified type II SMA.
6) According to the results of the flexural fatigue test on two-layer specimen, in the case of the HP-SMA applied to the upper layer, the lower layer and both the upper and the lower layers, the number of load cycles to rupture is about twice, 8 times and 40 times, respectively, as great as that in the case of the modified type II SMA applied to both the upper and the lower layers.

## 6.3 Applicability on an in-service road

1) In the case of the HP-SMA overlaid in a single layer on the concrete slab:
   When reflective cracks over the entire width were initiated at 24% of the joints in the ordinary paving section (with a 1-cm thick stress absorbing membrane interlayer), the paving section with the HP-SMA showed only slight cracks at some of the joints without cracks over the entire width.
2) In the case of the HP-SMA applied to the underpart of the overlay:
   Where the existing asphalt pavement had been overlaid with a 4-cm thick layer of the HP-SMA and then with a 2-cm thick layer of porous asphalt concrete without removing reflective cracks initiated at the joints, no reflective cracks were observed after the lapse of more than two years.

## CONCLUSION

The reflective cracking inhibition effect of the SMA with the modified asphalt that was newly developed, aiming at stress relaxation, was confirmed by laboratory testing and test application on an in-service road. As a result, the effectiveness of the HP-SMA for inhibition of reflective cracking was verified.

For the future, we intend to further continue our long-term follow-up survey to accumulate data and thereby to verify the effectiveness of the present paving method for maintenance and repair, adding a lifecycle “twist.”

Being not only excellent in reflective cracking inhibition effect, resistance to cracking and rutting resistance, but also elaborate, the HP-SMA is superior in wear resistance and weather resistance. Therefore, this mixture can be considered suitable for the surface, intermediate and base courses of longer-lasting pavements. We intend to continue studies on these matters as well.

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